Cement Grinding Systems

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1. OVERVIEW GRINDING SYSTEMS

The common cement grinding systems are summarized in Figure 1 and can be divided up into three main groups:

Tube Mill only

All grinding work is done in the tube mill and the set-up is:

- Tube mill in open circuit
- Tube mill in closed circuit with
  - Mechanical air separator
  - Rotor type separator

Tube Mill with Pregrinding Unit

A part of the grinding work is done in a pregrinding unit which can be:

Roller press

Vertical shaft impact crusher

Vertical roller mill (without separator, only grinding tool is used or with separator)

Depending on the selected system, the tube mill is in open or closed circuit (in most applications the tube mill is in closed circuit).

Finish Grinding System

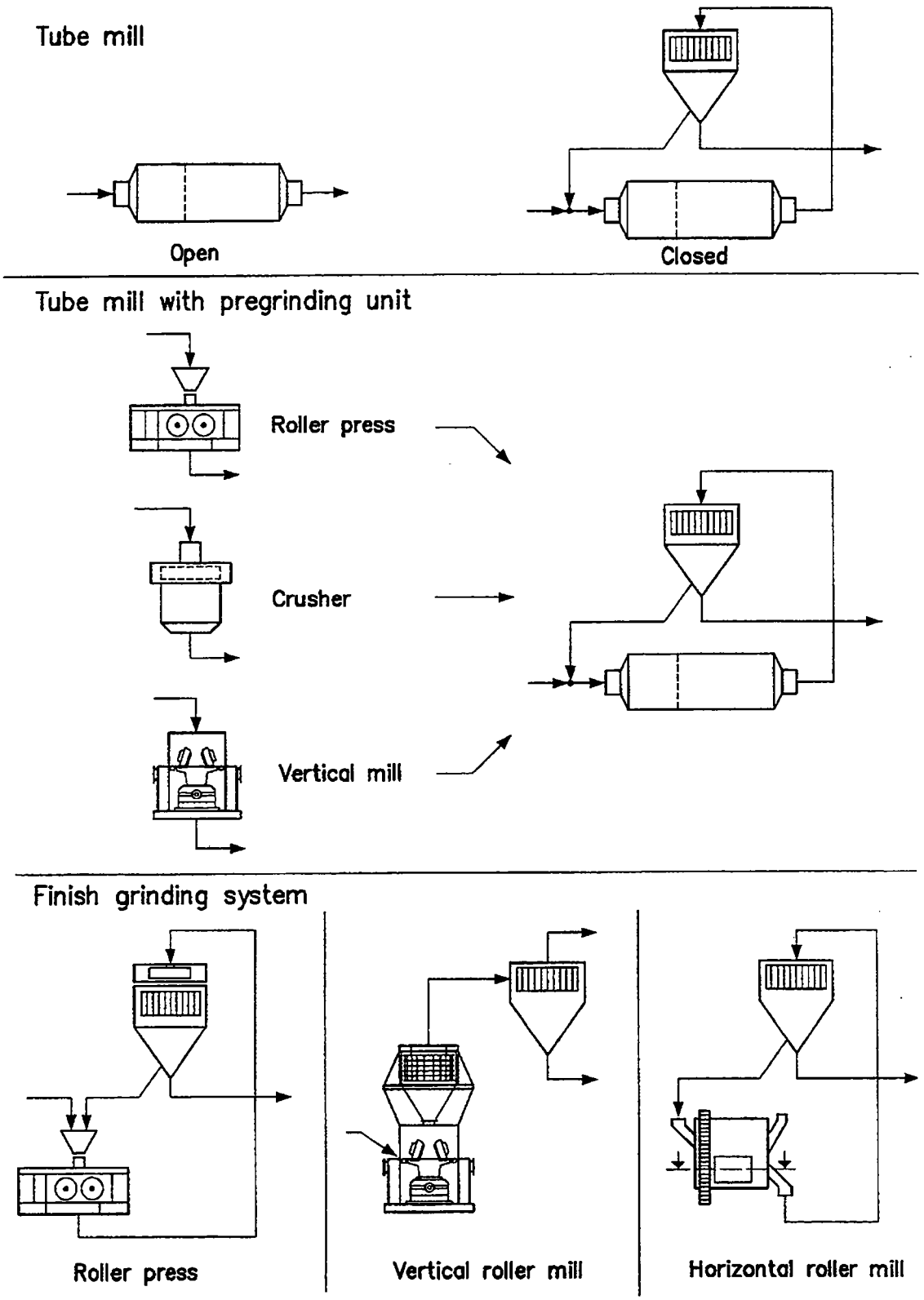
The tube mill is omitted and all grinding work is done in a more efficient comminution machine. The possible systems are:

Roller press with desagglomerator and rotor type separator

Vertical roller mill with integrated rotor type separator

Horizontal roller mill with rotor type separator

Figure 1: Overview



2. REQUIREMENTS

The requirements on a cement grinding system are manifold and a profound investigation and valuation of all criteria is necessary in order to find the appropriate solution (technically and economically) for:

Procuring of a new grinding system

Expanding and optimizing an existing system

The common criteria are summarized in Figure 2 and the most important will be further discussed.

Production - Cement Types

From a process point of view the grouping is:

- Portland cement 2'500 - 6'000 [cm^2/g]
- Portland cement with minor additive ≤ 5 [%] 2'500 - 6'000 [cm^2/g]
- Composite or blended cement, additive > 5 [%] 2'500 - 9'000 [cm^2/g]

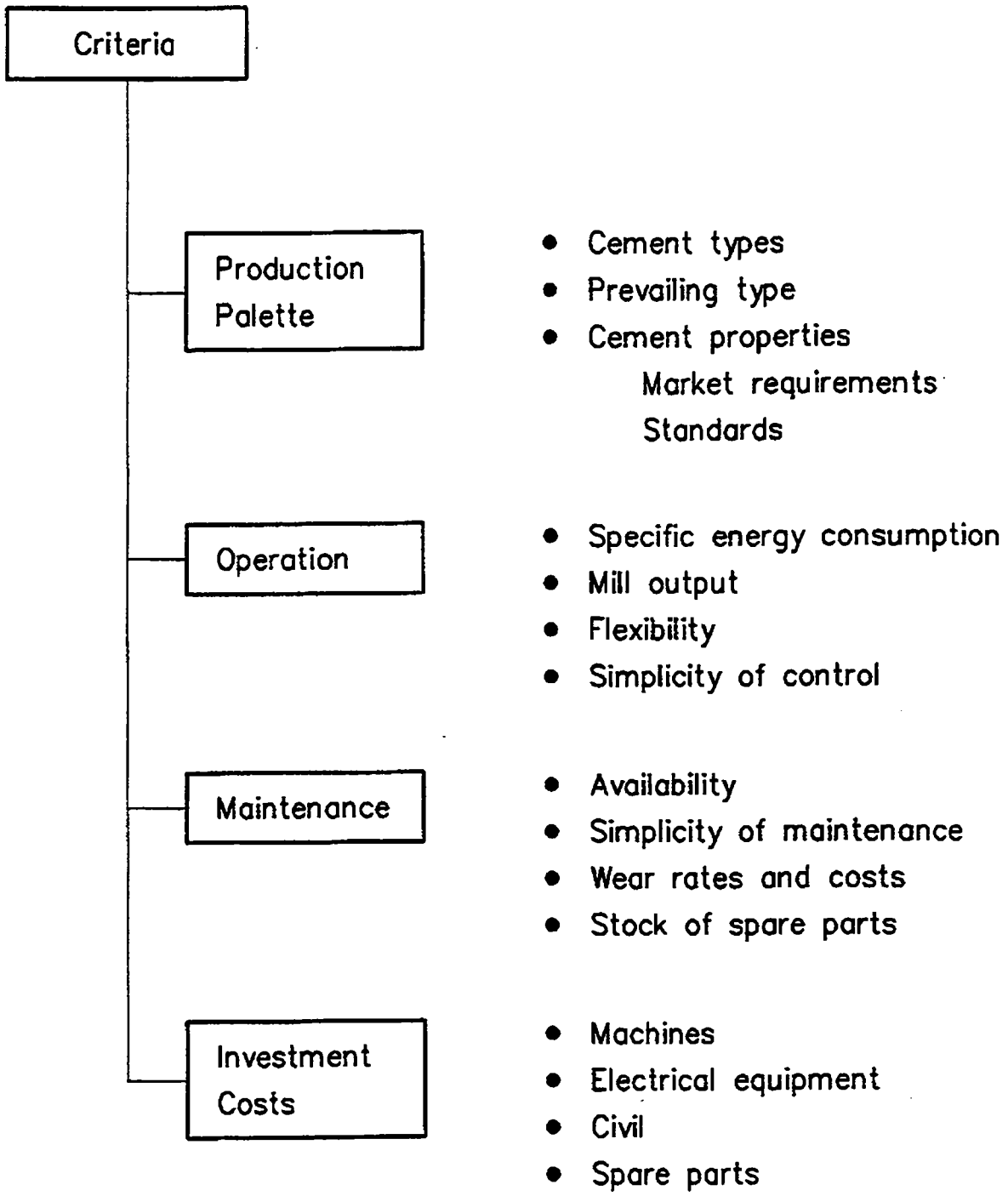
  Possible additives for composite cements are:
  Fly ash, pozzolana, blast furnace slag, limestone,
  silica fume, calcined clay etc.

A system must be able to grind one or several of above cement types to the required fineness at the lowest possible energy consumption.

In case of Portland cements cooling must be performed within the system.

In case of composite cements drying within the system is often a need and components with different grindabilities must be interground.

Figure 2: Requirements



Production - Cement Properties

The cement properties are influencing the:

- Workability of the concrete
- Early and late strength

The necessary values are given by the market requirements and the standards.

The cement properties are mainly influenced by:

- Composition of the cement
- Chemical and mineralogical composition of components
- Reactivity of clinker
- Particle size distribution, particle shape
- Sulphate agent:
  - Distribution and fineness
  - Modification and its solubility

The grinding system has influence on:

Particle Size Distribution and Shape

The particle size distribution is presented in the RRSB-diagram as shown in Figure 3 and characterized by:

- Steepness of distribution n
- Limiting particle d' (36,8 [%] R)

The steepness is depending on the type of grinding system, as shown in Figure 3, and can be adjusted within a certain range.

Without considering the chemical-mineralogical influences often the tendency is, going from wide to narrow distribution:

Early strength → decrease

Late strength → increase

Workability → worsening

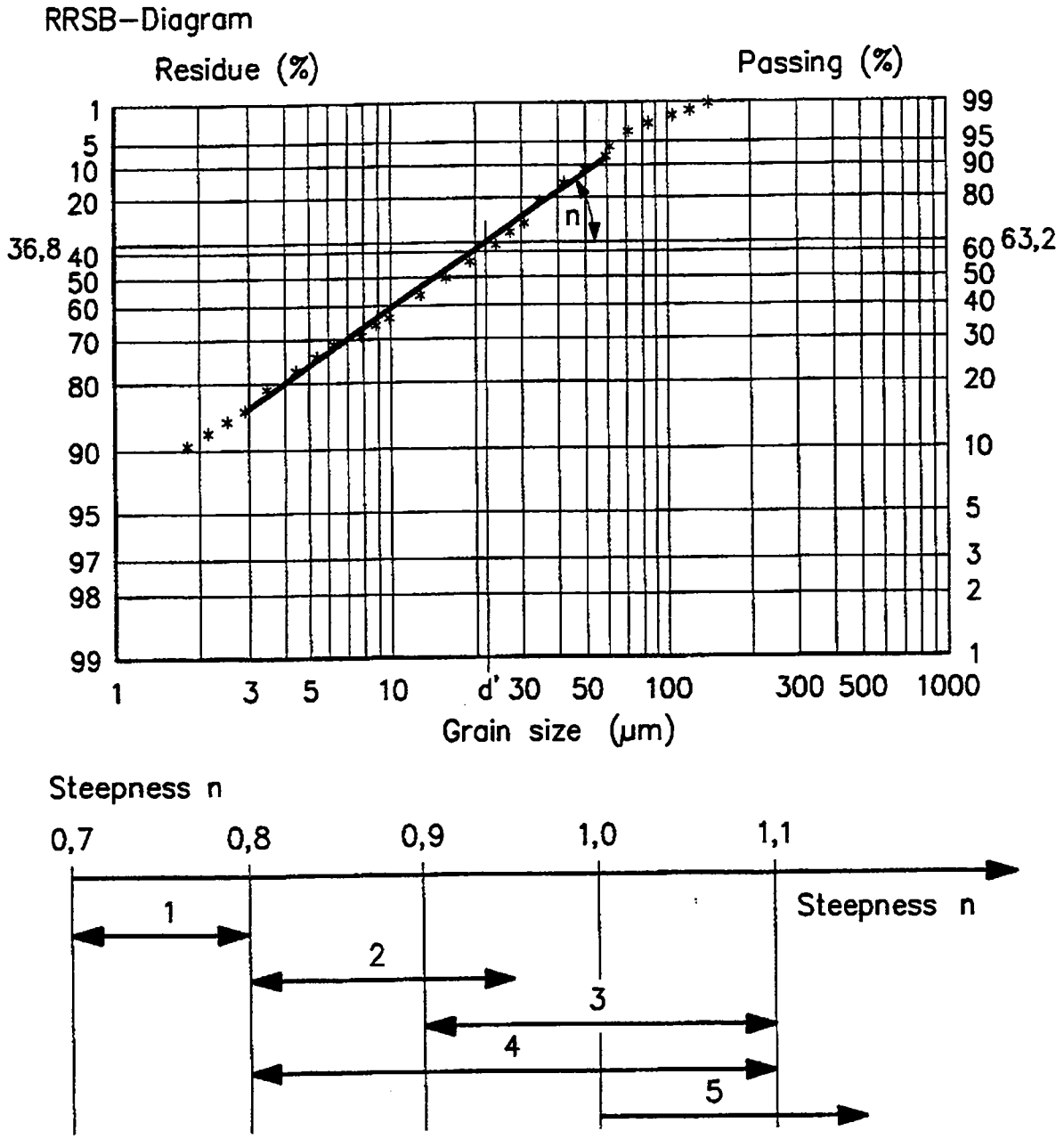
The particle shape can be characterized (simplified):

Round shape → Tube mill system (grinding by friction)

Angular shape → Finish grinding system (grinding by compression)

Angular shape could result in a higher water requirement.

Figure 3: Particle Size Distribution



1 Open circuit
2 Closed circuit mechanical air separator
3 Closed circuit rotor type separator
4 Tube mill with pregrinding unit (depending separator)
5 Finish grinding system

Sulphate Agent

In order to achieve the optimal workability of concrete an adaptation of clinker reactivity, particle size distribution and soluble calcium sulphate is a need. The relation can be simplified as follows:

Clinker reactivity	Particle size distribution	Easily soluble $CaSO_4$
Low	Wide	Low
Low	Narrow	Medium
High	Wide	High
High	Narrow	Very high

Clinker reactivity low $C_3A < 8$ [%], $Na_2O_{eqv.} < 0,6$, SR > 2,7

Clinker reactivity high $C_3A > 11$ [%], $Na_2O_{eqv.} > 0,9$, SR < 2,3

Particle size distribution wide $n < 0,9$

Particle size distribution narrow $n > 1,0$

Solubility of sulphate agent:

The modification of the sulphate agent is

- Dihydrate — fed to the mill as "gypsum"
- Hemihydrate } produced in the mill under high
- } temperature from dihydrate
- Soluble anhydrite }
- Natural anhydrite — fed to the mill as "gypsum"

The solubility is increasing in the sequence:

- Natural anhydrite
- Dihydrate
- Soluble anhydrite / hemihydrate

If supply of easily soluble sulphate is short

→ flash set can occur

If oversupply exists

→ false set can occur

If high amount of easily soluble sulphate is required, cement must be ground at high temperature.

The following grinding systems are producing a narrow particle size distribution at a low grinding temperature:

- Tube mill in closed circuit with rotor type separator with product collection in bag filter (cooling in separator)
- Finish grinding system with roller press
- Finish grinding system with vertical roller mill and horizontal roller mill (less critical)

If the clinker has in addition a high reactivity the system must be laid out in such a way that:

- Steepness of particle size distribution can be adjusted
- Cement can be ground at high temperature

Operation - Specific Energy Consumption

The total specific energy consumption of a grinding system is depending on a multitude of factors:

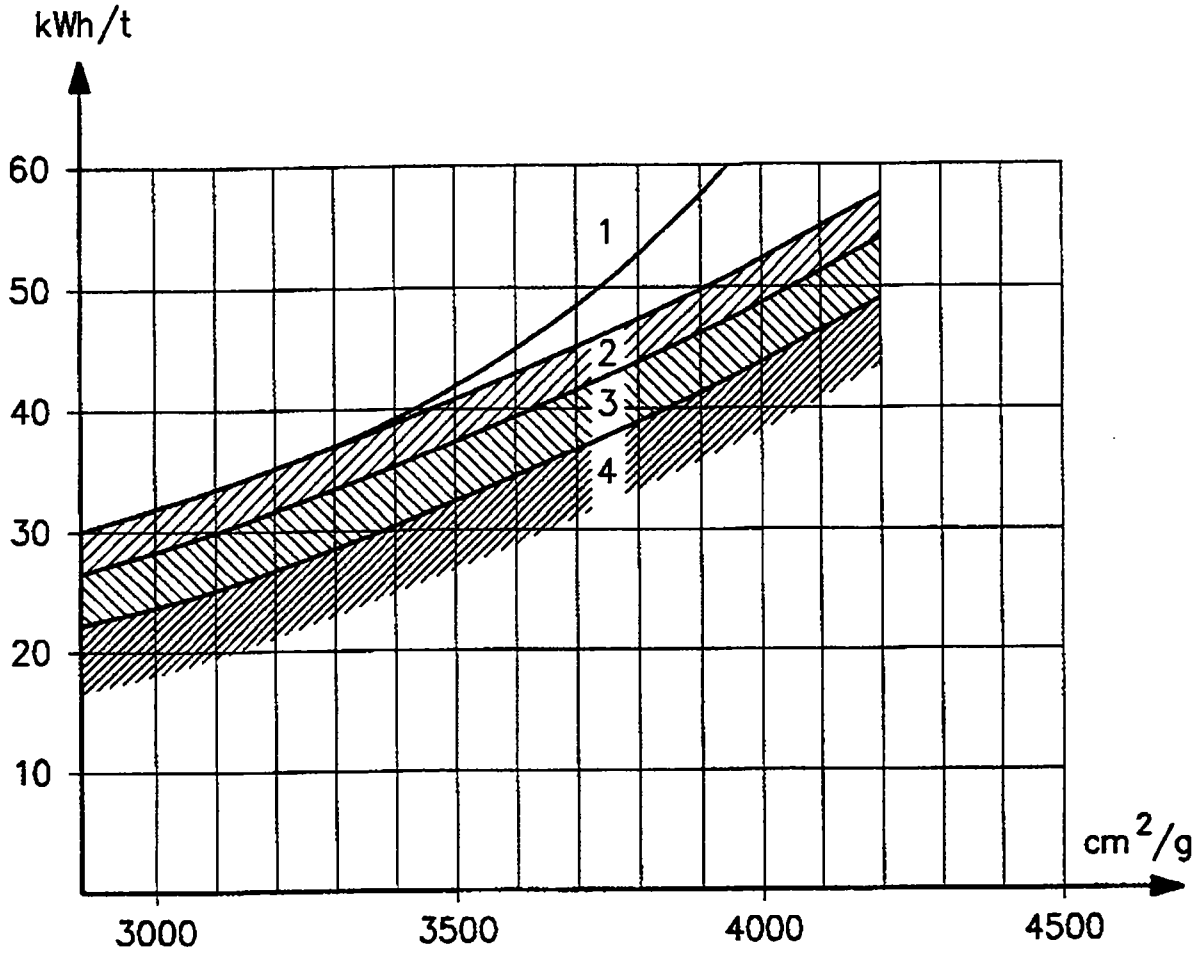
- **Type of grinding system**

  The highest influence on the energy consumption has the type of system. Figure 4 gives a comparison between tube mill open circuit, closed circuit, tube mill with pregrinding unit and finish grinding system. The given [kWh/t] in relation to fineness [cm^2/g] should only indicate at which level the individual systems are and are not absolute values.

Further factors are:

- **Mill feed**
  - Composition
  - Grindability of components
  - Grain size distribution
  - Moisture content of additive
- **Technical condition**
  - Main machines
  - Wear parts in general
  - Mill internals, ball charge etc.
- **Mill control**
  - Manual
  - Automatic (High Level Control)
- **Use of grinding aid**

Figure 4: Specific Energy Consumption



1 Tube mill open circuit
2 Tube mill closed circuit
3 Tube mill with pregrinding unit
4 Finish grinding system

3. GRINDING SYSTEMS

3.1 Tube Mill Systems

3.1.1 Tube Mill in Open Circuit (Figure 5)

Main Elements of System

1) Feed bins with weigh feeders
2) Tube mill with two or three compartments
3) Mill filter: Electrostatic precipitator or bag filter
4) Metal trap: Vibratory screen
5) Cement cooler: Not standard outfit

Judgement

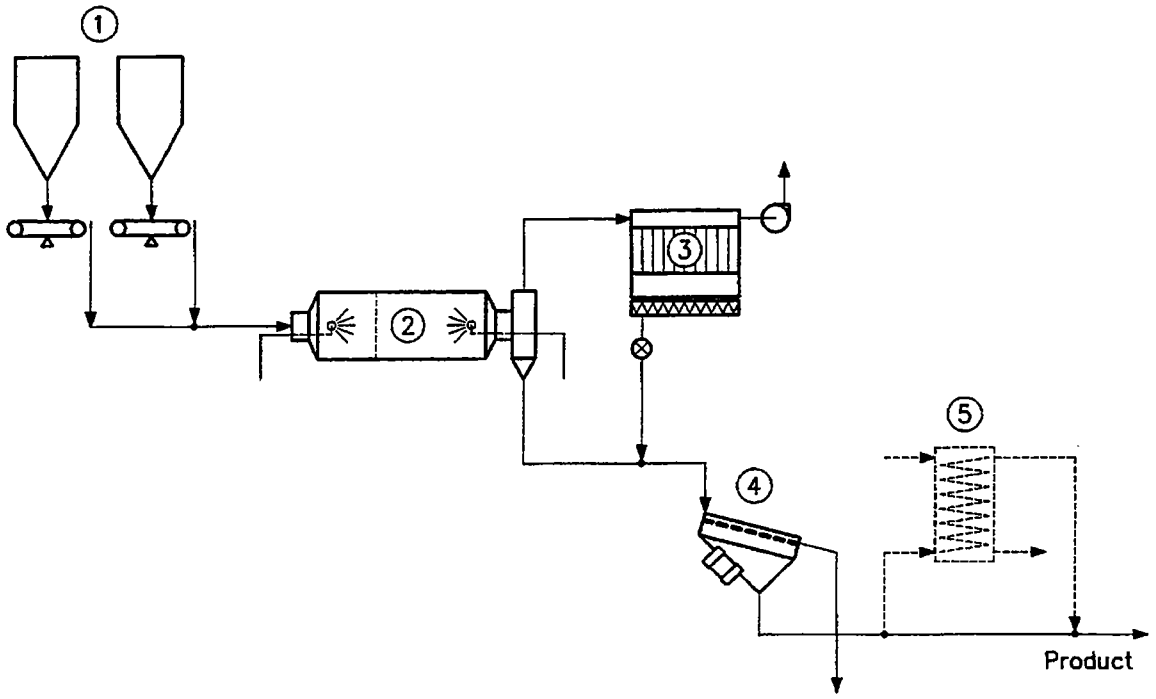
- **Production**
  Suited for Portland cement with low fineness.
  Not recommended if several types must be ground.
  Product characterized by wide particle size distribution.
- **Operation**
  Specific energy consumption high for fineness > 3'000 [cm^2/g].
  Mill output up to 200 [t/h].
  Product temperature high. Cooling by mill ventilation and water injection: Due to limited ventilation often cement coolers are required.
  Sensitive to variation in mill feed grindability and granulometry.
- **Maintenance**
  High availability of system.
  Simple to maintain and proven wear parts.

Comment

The tube mill in open circuit can not be recommended for new installations (exception combination with pregrinding unit).

Conversion to closed circuit often recommendable due to more flexibility and reduced energy consumption.

Figure 5: Tube Mill in open circuit



3.1.2 Tube Mill in Closed Circuit

System with mechanical air separator (Figure 6)

Main Elements

1) Feed bins with weigh feeders
2) Tube mill with two compartments
3) Mechanical air separator
   Configurations: 1 or 2 mechanical air separators
   Separator with/without dedusting
4) Mill filter: Electrostatic precipitator or bag filter with/ without prededusting in static separator or cyclone 4a
5) Cement cooler: Not standard outfit

Judgement

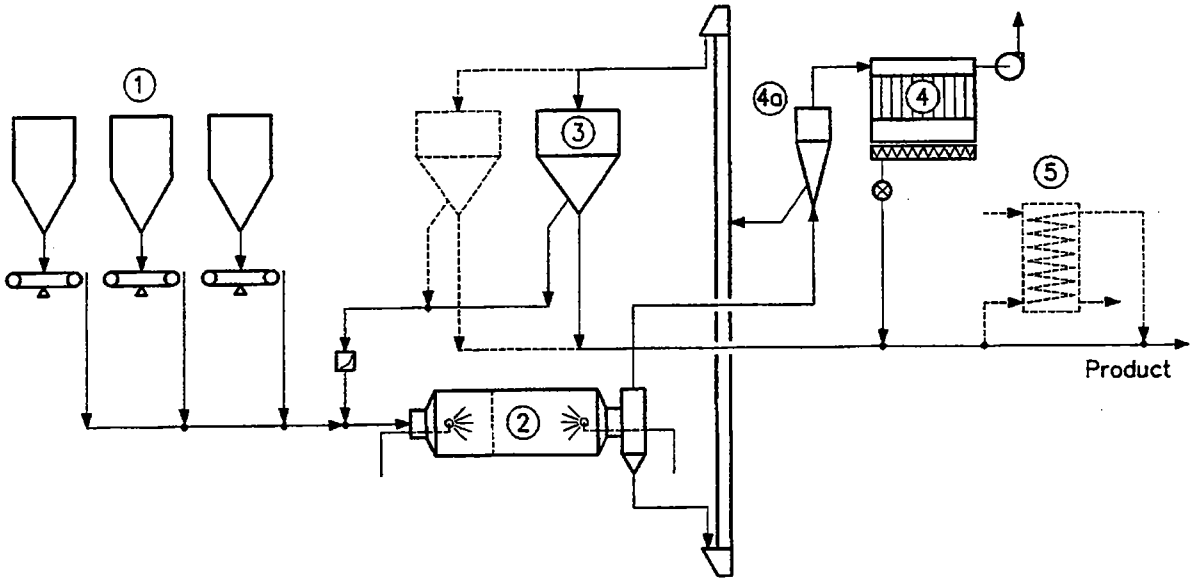
- **Production**
  Suited for Portland cement, Portland cement with minor additives and composite cements (if equipped accordingly e.g. hot gas generator).
  Product characterized by wide to medium particle size distribution.
- **Operation**
  Specific energy consumption medium to high depending on product fineness.
  Mill output up to 200 [t/h].
- Product temperature medium. Cooling by mill ventilation and water injection: Optionally by fresh air in separator and/or cement cooler.
  Variations in mill feed grindability can be equalized.
- **Maintenance**
  High availability of system.
  Simple to maintain and proven wear parts.

Comment

Most commonly used system for cement grinding.

Not recommended for new installations due to separator design.

Figure 6: Tube Mill in closed circuit, Mechanical Air Separator



System with rotor type separator (Figure 7)

Main Elements

1) Feed bins with weigh feeders
2) Tube mill with two compartments
3) Rotor type separator
   Configurations: 3 rotor type separator with bag filter
   3a rotor type separator with cyclones and small dedusting bag filter
4) Mill filter: Bag type
   Cement cooler: Not standard outfit and mainly in combination with rotor type separator with cyclones

Judgement

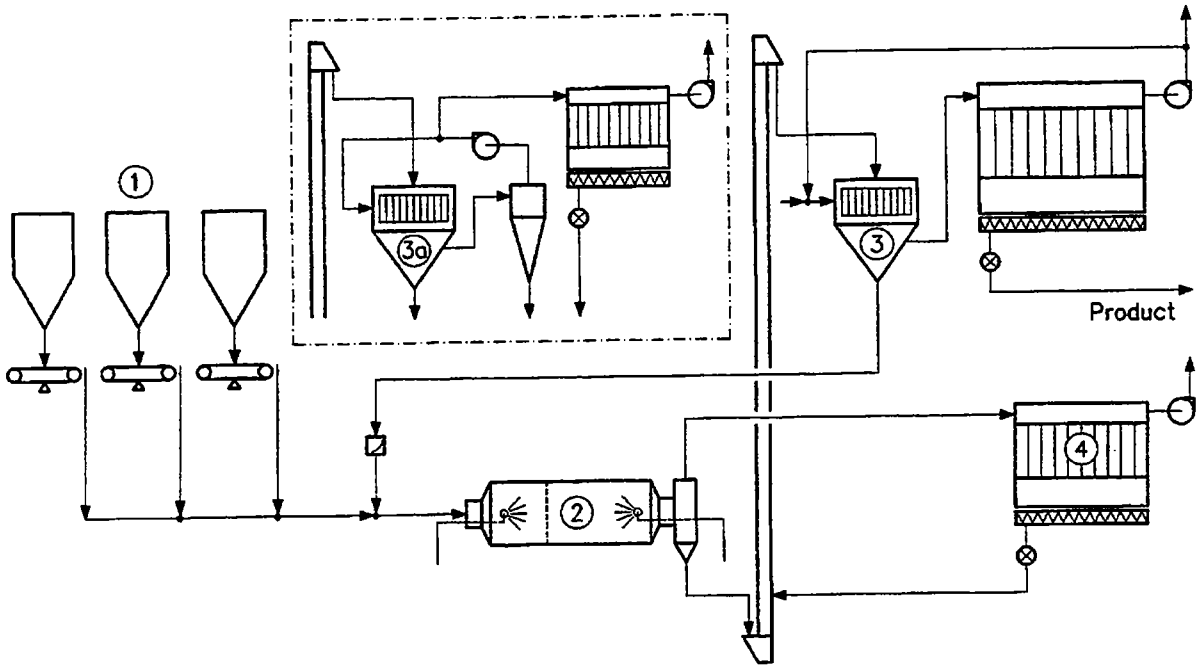
- **Production**
  Suited for Portland cement, Portland cement with minor additives and composite cements (if equipped accordingly).
  Product characterized by narrow particle size distribution.
- **Operation**
  Specific energy consumption medium to low.
  Mill output > 200 [t/h].
  Product temperature medium:
  - Configuration 3 - Product respectively grinding temperature low. Cooling by mill ventilation and fresh air supply to separator.
  - Configuration 3a - Product temperature medium. Cooling by mill ventilation and water injection and optionally by cement cooler.
- **Maintenance**
  High availability of system.
  Simple to maintain and proven wear parts.

Comment

Suitable for new installations.

Possibility for conversion of old systems from open to closed or for replacement of mechanical air separators.

Figure 7: Tube Mill in closed circuit, Rotor Type Separator



3.2 Tube Mill Systems with Pregrinding Unit

3.2.1 Roller Press

The roller press in front of the tube mill takes over a part of the grinding work of the mill. Size reduction in a press is more efficient than in a tube mill.

Basic configurations are (Figure 8):

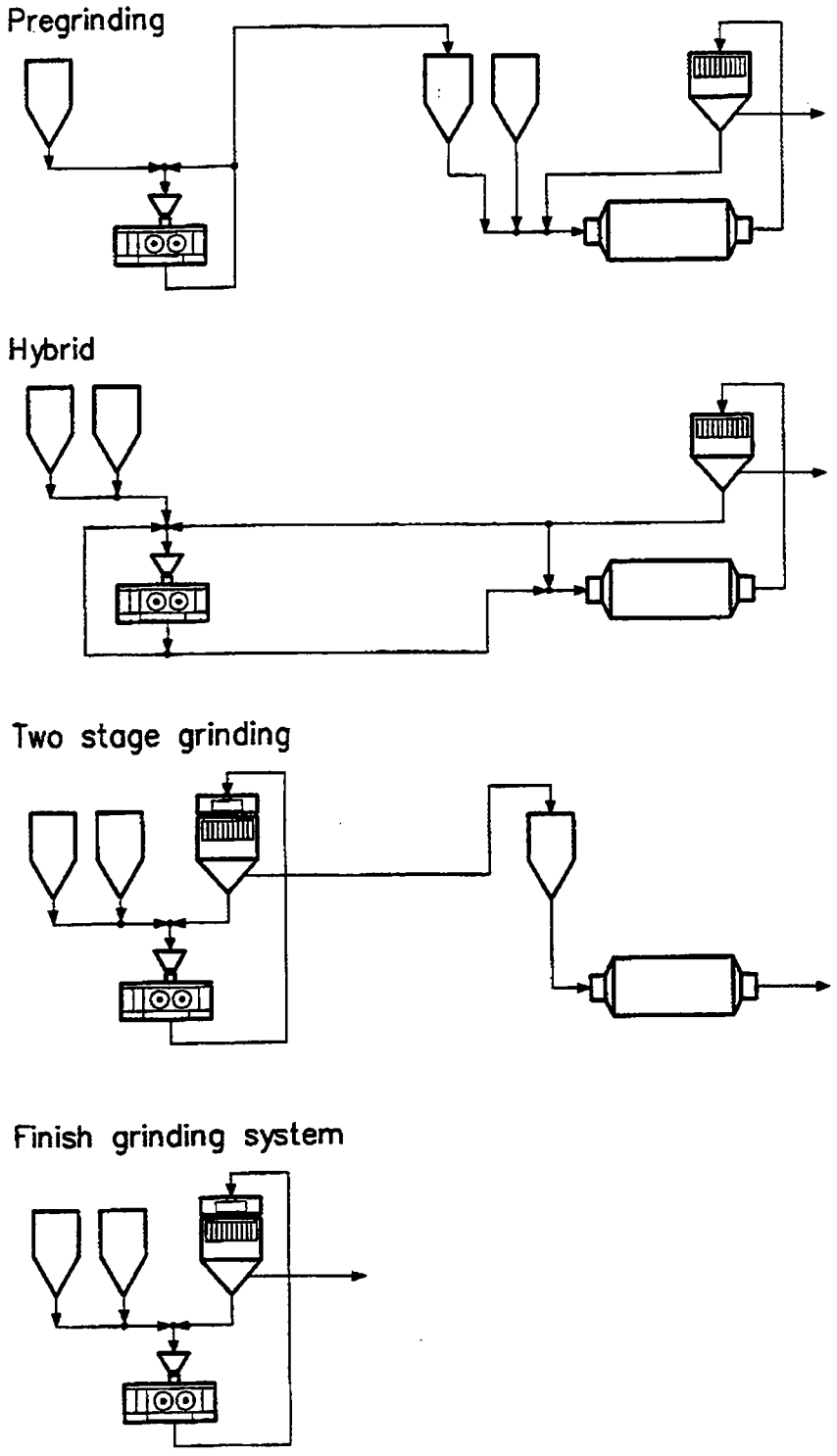
- **Roller press in pregrinding mode**
  Press independent of tube mill, can serve several mills.
  Type of tube mill: Closed circuit with mechanical air separator or rotor type separator.
  Power relation: Press : mill ~ 20 : 80 [%].
- **Hybrid system**
  Press linked together with tube mill, can serve only one mill.
  Type of tube mill: Closed circuit with mechanical air separator or rotor type separator.
  Power relation: Press : mill ~ 30 : 70 [%].
- **Two stage grinding system**
  Press equipped with separator and desagglomerator, with/without intermediate storage, press could serve several mills.
  Type of tube: Closed or open circuit.
  Power relation: Press : tube mill ~ 50 : 50 [%].
- **Finish grinding system**
  Press equipped with separator and desagglomerator.
  Cement is ground in roller press only.

Rule of Thumb

1 [kW] absorbed in the press replaces 2 - 2,5 [kW] in the tube mill.

If roller press is used as a retrofit for existing systems, capacity increases of 25 up to 100 [%] can be achieved.

Figure 8: Configurations with Roller Press



3.2.1.1 Hybrid / Pregrinding System

Main Elements (Figure 9)

1) Press feed bins with weigh feeders (e.g. clinker, gypsum)
2) Roller press
3) Overflow bin or dividing gate for slabs
4) Additional mill feed bin (e.g. for wet additive)
5) Tube mill with two compartments
6) Rotor type separator: With bag filter or with cyclones
7) Mill filter: Bag type
8) Overflow bin or dividing gate for separator coarse material (not required if in pregrinding mode)

Operation of Roller Press

The press is fed by fresh feed, slabs and coarses from the separator. If the latter is set zero the press works as a pregrinding system with slab recirculation only.

Judgement

Production
Suited for all cement types if equipped accordingly.
Product characterized by narrow particle size distribution.

Operation
Specific energy consumption low.
Mill output > 200 [t/h].
Product temperature depends on selected separator (see chapter 3.1.2: System with rotor type separator).
System can be operated also without roller press.

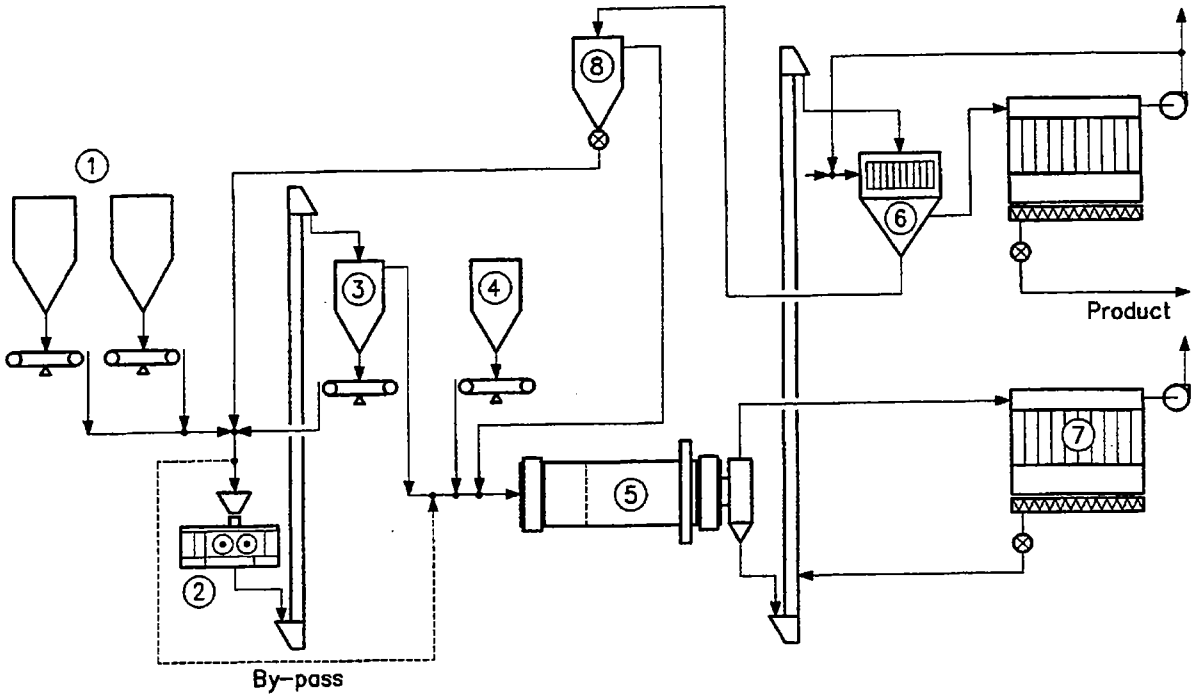
- **Maintenance**
  Roller press: Low wear but very sensitive to foreign matters (metal etc.) Wear protection reconditioning rollers still in a development phase.
  System: Availability is depending on roller press.

Comment

Suitable for new installations (only pregrinding system).

Possibility for capacity increase of existing systems.

Figure 9: Hybrid System



3.2.1.2 Two Stage Grinding System

Main Elements (Figure 10)

1) Press feed bins with weigh feeders (clinker, gypsum)
2) Roller press
3) Rotor type separator with desagglomerator
   Separator with bag filter or cyclones
4) Intermediate bin with weigh feeder
5) Tube mill with one or two compartments (open or closed circuit)
6) Mill filter: Bag type
7) Rotor type separator: with bag filter or cyclones
8) Bin for additive with weigh feeder

Judgement

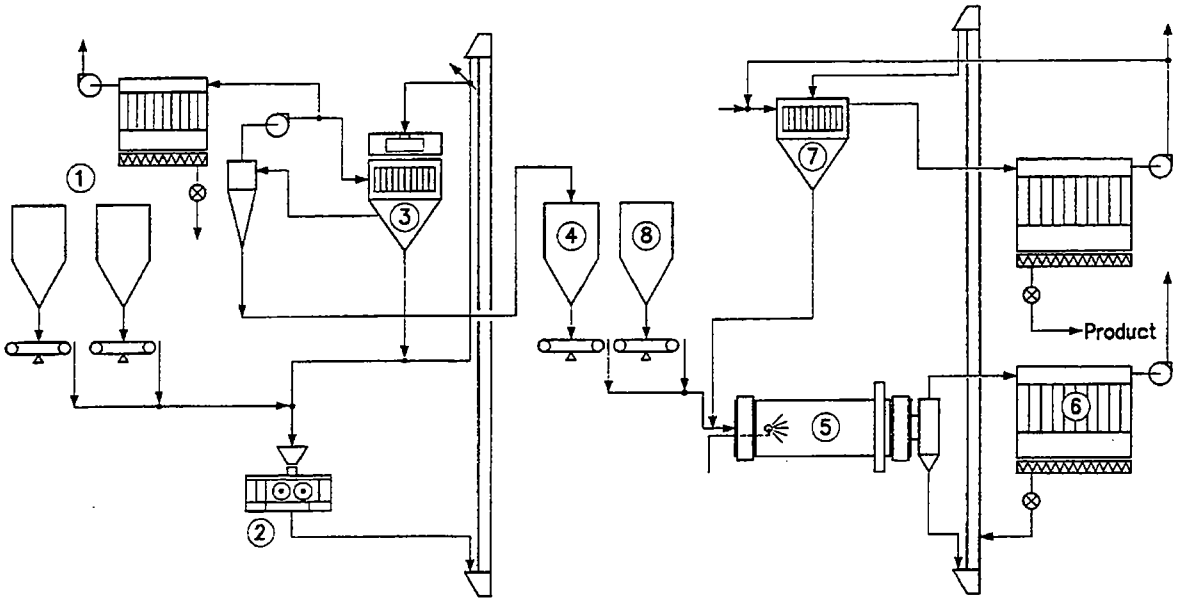
- **Production**
  Suited for Portland cement and also for composite cement; the additive can be fed directly to the tube mill.
  In the first stage (press with separator) the cement is ground 1'000 - 1'500 [cm^2/g] below desired product fineness and in the tube mill to the end fineness.
  Product characterized by medium to narrow steep grain size distribution.
- **Operation**
  System can only be operated without roller press if two compartment mill
  Specific energy consumption low.
  Max. mill output given by fineness and available press size ~ 150 - 200 (t/h).
  Product temperature medium to low. Cooling by mill ventilation, separator cooling and water injection.
- **Maintenance**
  Roller press: Low wear but very sensitive to foreign matters.
  Wear protection reconditioning rollers still in a development phase.
  System: Availability is depending on roller press.

Comment

Suitable for new installations (not favoured, complicated).

Possibility for capacity increase of existing systems.

Figure 10: Two Stage Grinding System



3.2.2 Vertical Shaft Impact Crusher

The vertical shaft impact crusher in front of the tube mill takes over a part of the grinding work from the first compartment of a tube mill. The material is crushed to μ 3 [mm].

Basic configurations are (Figure 11):

- **Vertical shaft impact crusher in open circuit**
  Material passes only once through the crusher.
  Crusher independent of mill, could serve several mills.
  Type of tube mill: Any type of mill.
- **Vertical shaft impact crusher in closed circuit**
  System works in closed circuit with vibratory screen. Due to screen sensitive against moisture in feed.
  Crusher independent of mill, could serve several mills.
  Type of tube mill: Any type of mill.

Comment

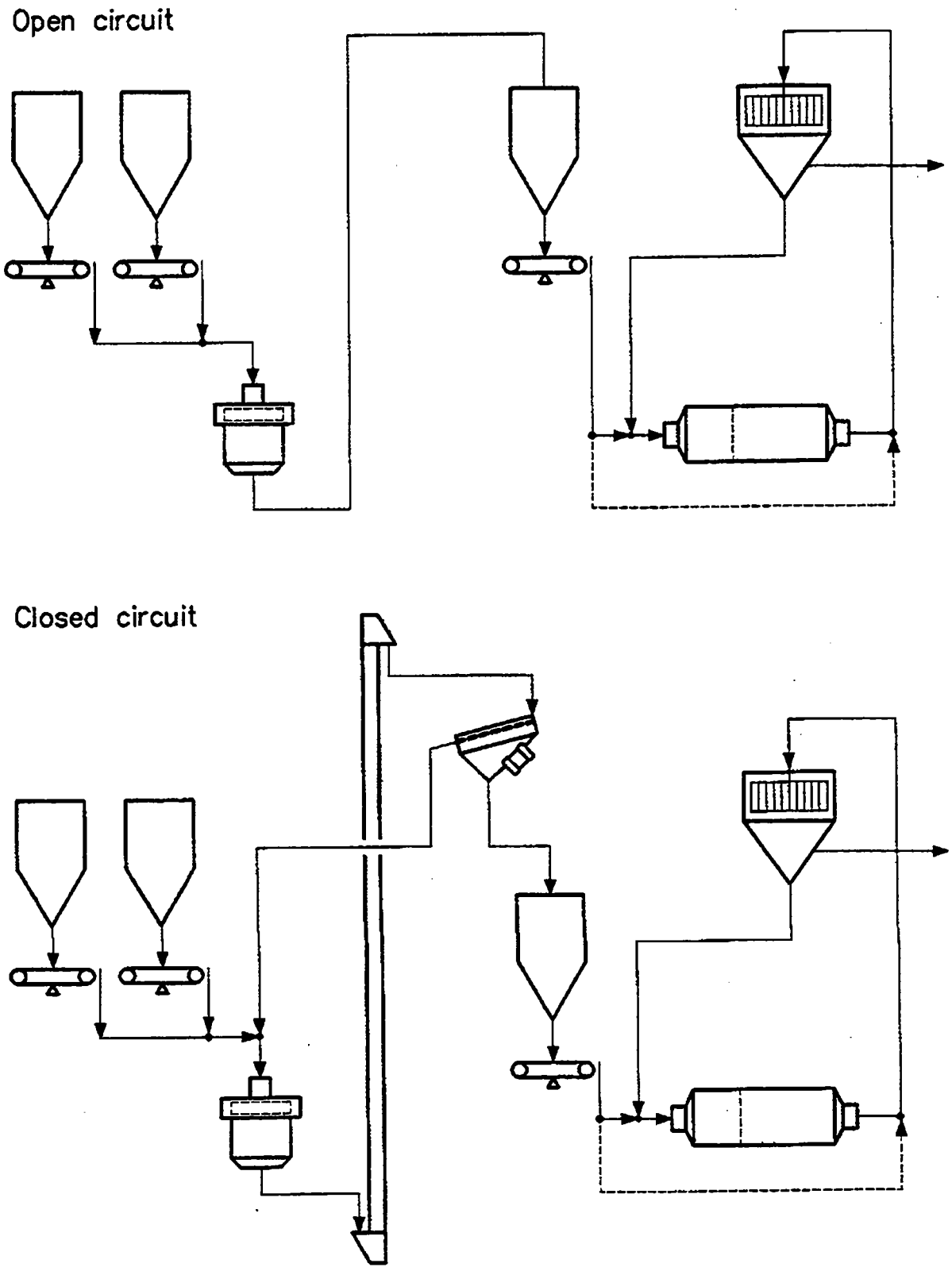
The utilization of the crusher is mainly seen as a retrofit for existing systems in order to increase grinding capacity and not for new installations.

Achievable increase: 15 - 20 [%].

Reduction specific energy consumption: 2 - 3 [kWh/t].

The application of the crusher is only sporadically.

Figure 11: Vertical Shaft Impact Crusher



3.2.3 Vertical Roller Mill

The vertical roller mill, as known from the raw grinding, can be used as pregrinding machine. The basic mill design is as for raw grinding, however, the grinding tools, hydraulic system and drive are adjusted for clinker grinding. The mill is supplied with or without separator.

Possible configurations are (Figure 12):

- **Closed circuit with recirculation**
  Comparable with roller press with slab recirculation.
- **Closed circuit with screen**
  In both cases, the vertical mill can serve one or several tube mills. The feed size to the tube is ≤ 3 [mm].
- **Two stage grinding system**
  Comparable with roller press in two stage mode.

Comment

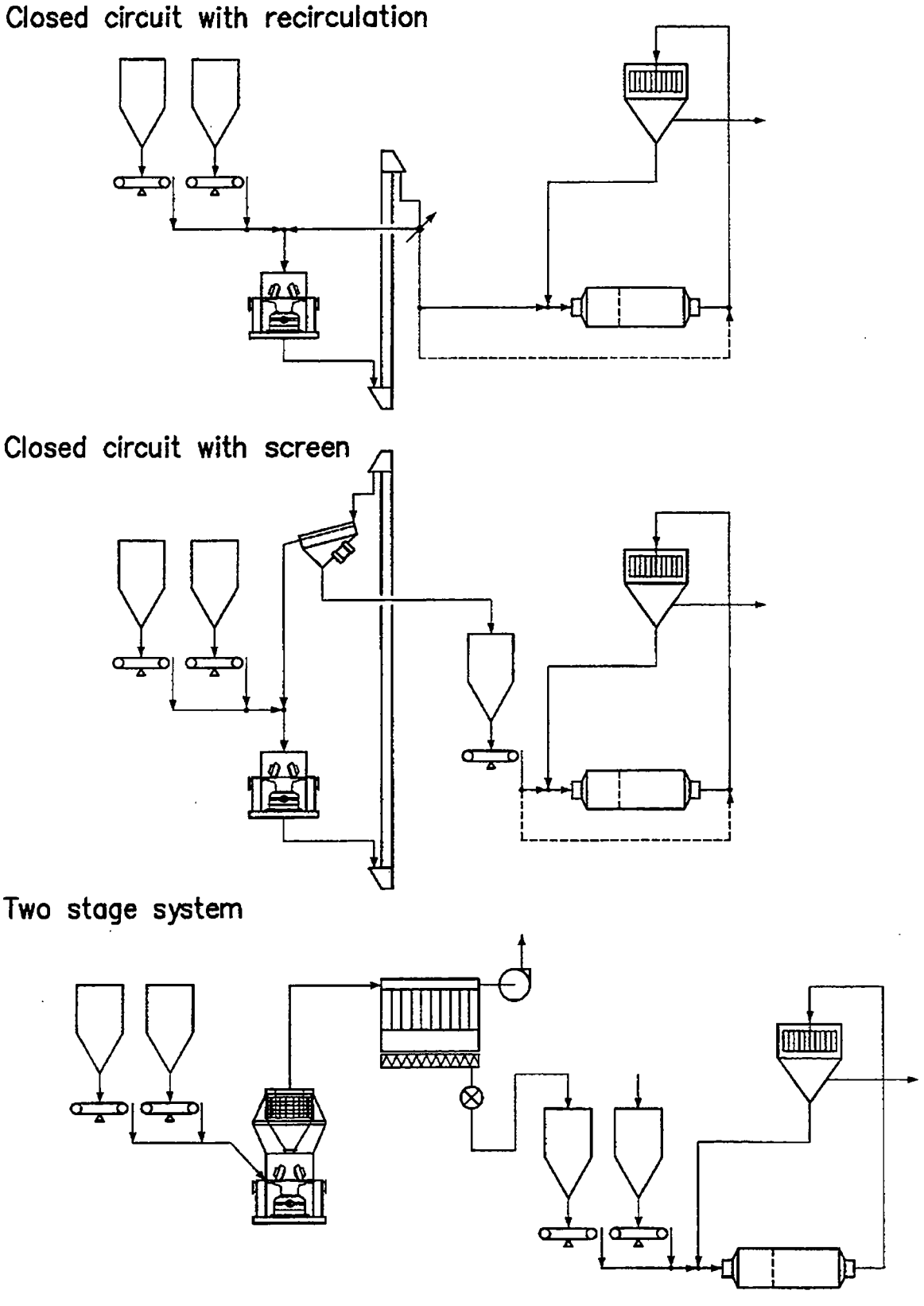
The achievable results are comparable with the roller press.

If the vertical mill is used as a retrofit for existing systems, capacity increases of 25 up to 100 [%] can be achieved depending on the configuration.

1 [kW] absorbed in the vertical mill replaces 2 - 2,5 [kW] in the tube mill.

The application of the vertical roller mill can mainly be found in the Far East (Japanese suppliers).

Figure 12: Vertical Roller Mill



3.3 Finish Grinding Systems

3.3.1 Roller Press (Figure 13)

Main Elements

1) Feed bins with weigh feeders
2) Roller press
3) Desagglomerator
   Options: Desagglomerator combined with separator
   Separate desagglomerator
4) Rotor type separator
   Configurations: Separator with bag filter
   Separator with cyclones and dedusting bag filter
5) Slab recirculation (if required by process)
6) Cement cooler: Not standard outfit

Judgement

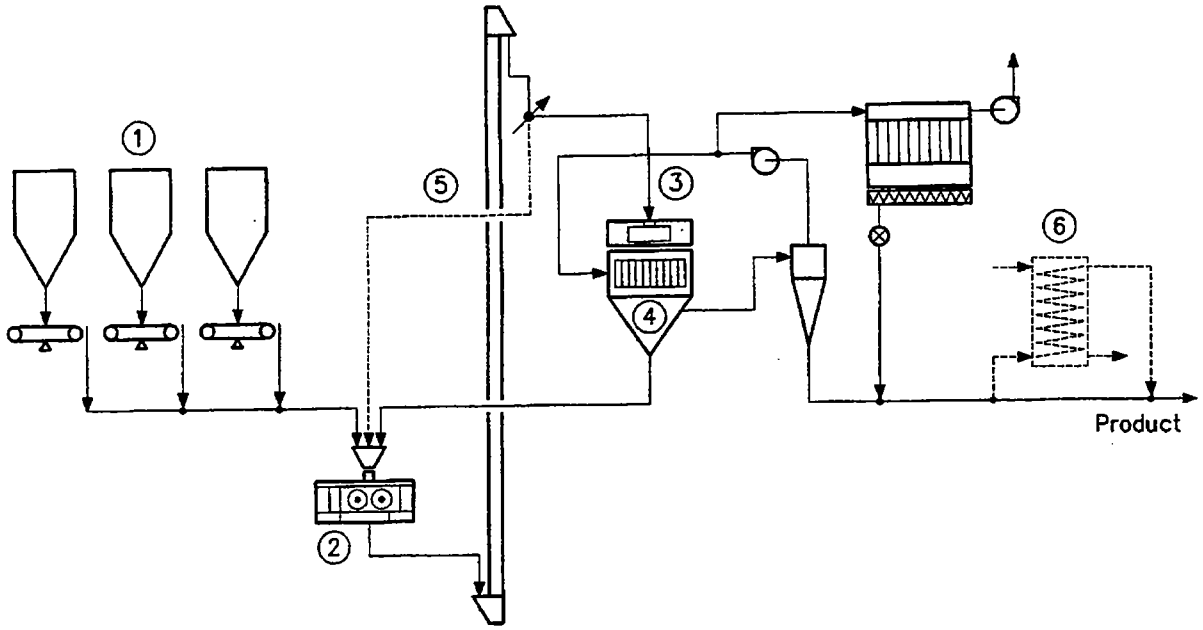
- **Production**
  Suited for Portland cement and Portland cement with minor additives.
  Product characterized by narrow particle grain size distribution (particles angular shape instead of round shape as from tube mill).
- **Operation**
  Specific energy consumption very low.
  Mill output limited by max. available press size and fineness ~ 120 - 140 [t/h].
  Product temperature medium to low depending on separator set-up. Cooling only by fresh air supply to separator. Optionally cement cooler for product.
- **Maintenance**
  Since new developed system, long term availability figures not assured. Reconditioning wear protection rollers still item which must be further developed.

Comments

Possible grinding system of the future for Portland Cement due to simplicity and low energy consumption. Quality problems could occure if clinker has high C_3A content. Not suited for blended cement.

Each new installation needs detailed investigations regarding product quality.

Figure 13: Finish Grinding System with Roller Press



3.3.2 Vertical Roller Mill (Figure 14)

Main Elements

1) Feed bins with weigh feeders
2) Vertical roller mill with integrated rotor type separator
3) Mill filter: Bag type
4) Auxiliary furnace: Not standard outfit, mainly used for composite cement

Judgement

- **Production**
  Suited for Portland cement, Portland cement with minor additives and composite cements (if equipped accordingly).
  Product characterized by medium to narrow particle size distribution.
- **Operation**
  Specific energy consumption very low.
  Product temperature medium to low. Cooling by fresh air supply to mill.
  If clinker has high reactivity, possibly hot gas has to be supplied to the mill.
  Mill output strongly dependent on wear rate of liners table and rollers (output decrease with increasing wear rate).
  Mill output limited by fineness and available mill sizes ~ 120 - 140 [t/h].
- **Maintenance**
  Expensive wear parts table and liners.
  Long term availability figures not assured.

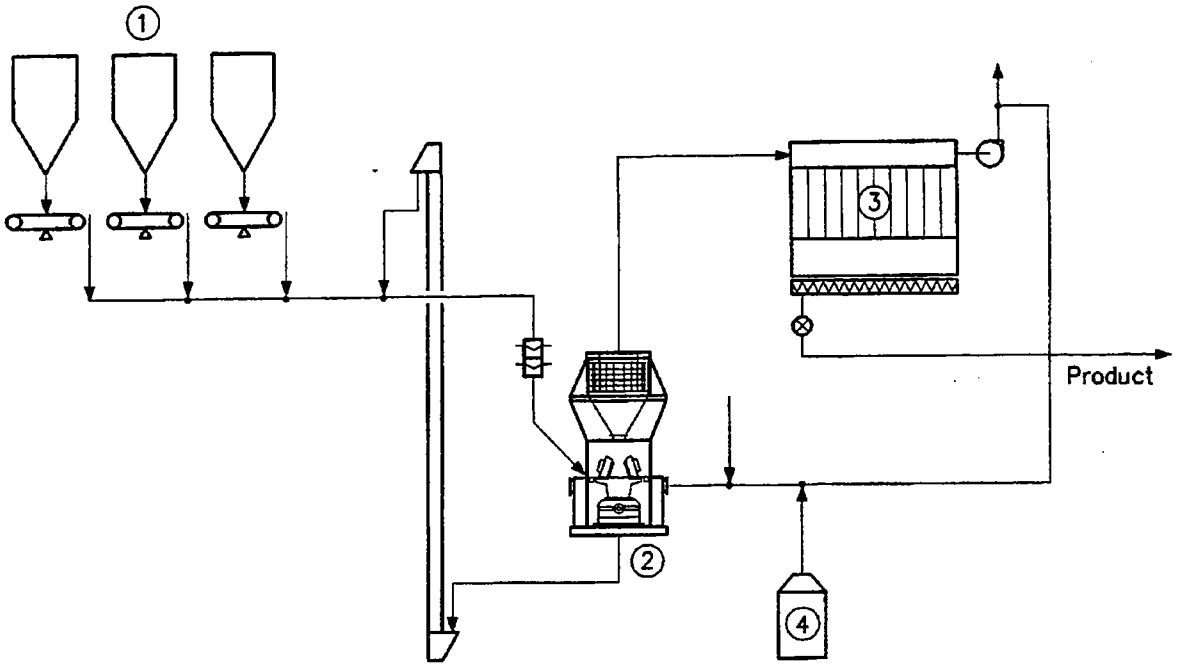
Comment

Alternatives to roller press system in finish grinding mode.

Not suited for all clinker types due to possible quality problems.

Good solution for composite cement due to excellent drying possibility.

Figure 14: Finish Grinding System with Vertical Roller Mill



3.3.3 Horizontal Roller Mill (Figure 15)

Main Elements

1) Feed bin mill weigh feeders
2) Horizontal roller mill
3) Rotor type separator with bag filter
   a) Rotor type separator with bag filter and flash dryer
4) Auxiliary furnace: not standard outfit, only used for composite cement where the additive has a high moisture and is fed directly to the flash dryer.

Judgement

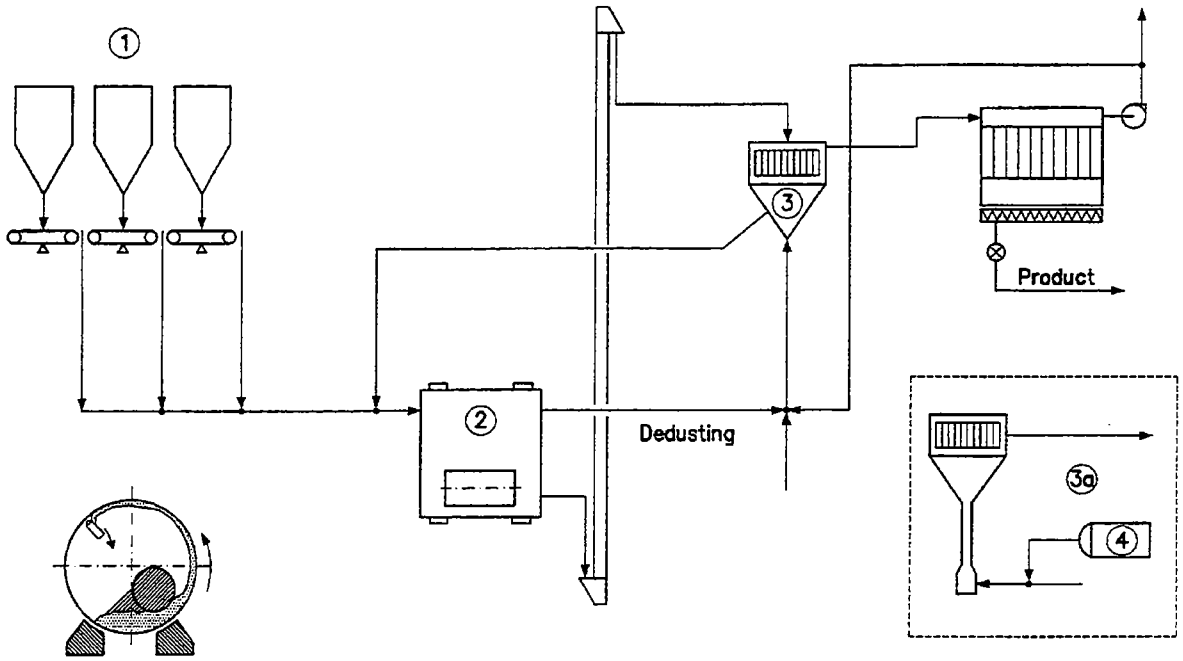
- **Production**
  Suited for Portland cement, Portland cement with minor additives and composite cements (if equipped accordingly).
  Product characterized by medium to narrow particle size distribution.
- **Operation**
  Specific energy consumption very low.
  Product temperature medium to low. Cooling by fresh air supply to separator (mill only dedusting).
  Mill output limited by fineness and available mill sizes ~120 - 140 [t/h].
- **Maintenance**
  Since new developed system, long term availability figures not assured.
  Wear problems similar to roller press.

Comment

Alternative to roller press and vertical mill.

Horizontal mills are still in a further development phase.

Figure 15: Horizontal Roller Mill



4. COMPARISON

For selecting a new system basically the following possibilities are given:

1. Tube mill closed circuit with rotor type separator

2. Tube mill closed circuit with roller press
2.1 Hybrid/pregrinding system
2.2 Two stage system

3. Finish grinding system
3.1 Roller press
3.2 Vertical roller mill
3.3 Horizontal roller mill

The following table summarizes important criteria in order to facilitate the selection:

	1	2		3		
		2.1	2.2	3.1	3.2	3.3
INVESTMENT COSTS [%]	100	110	120	100	110	110
SPECIFIC ENERGY [%]	100	85	75	60	70	65
PORTLAND CEMENT - LOW FINENESS - HIGH FINENESS	YES YES	YES YES	YES YES	YES LIMITED	YES LIMITED	YES LIMITED
COMPOSITE CEMENT	YES	YES	LIMITED	LIMITED	YES	LIMITED
CEMENT QUALITY	OK	OK	OK	*PARTLY OPEN	*PARTLY OPEN	*PARTLY OPEN
EXPANSION POSSIBILITY	YES	NO	NO	NO	NO	NO

*Partly open: Not recommendable if clinker is very reactive